JPL
Jet Propulsion Laboratory
California Institute of Technology

Planetary Science Summer School
Pasadena, CA

New Horizons in Systems Engineering

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Topics

- A few definitions
- The past
- The present
- The future
- A few conclusions

A Few Definitions

- System
  - A collection of hardware, software, people, facilities, and procedures organized to accomplish some common objectives - *IEEE*
  - A construct or collection of different elements that together produce results not obtainable by the elements alone. ... The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationships among the parts; that is, how they are interconnected. - E. Rechtin, *Systems Architecting of Organizations, 1999*

A Few Definitions

- **System Engineering**
  - **The process by which the design of a complex, multi-element system is technically coordinated and optimally matched, with constraints to the requirements on the system. In practice, System Engineering also assures that the delivered system is verified. - *System Engineering at JPL***
- **Architecting**
  - **Generally synthesis based, insightful, and inductive - R. Echtin, *Systems Architecting*, 1991**
- **Engineering**
  - **Generally analysis-based, factual, logical, and deductive - *ibid.***

The Past

- **Systems Engineering is a relatively new discipline**
  - **International Council On System Engineering (INCOSE) is only 10 years old.**
- **Traditionally focused on Requirements and Interface Documentation and (ultimately) Verification and Validation**
  - **some attempt at optimization of system design via trade studies (usually about a single point design)**
  - **frequently combined with System Architecting**

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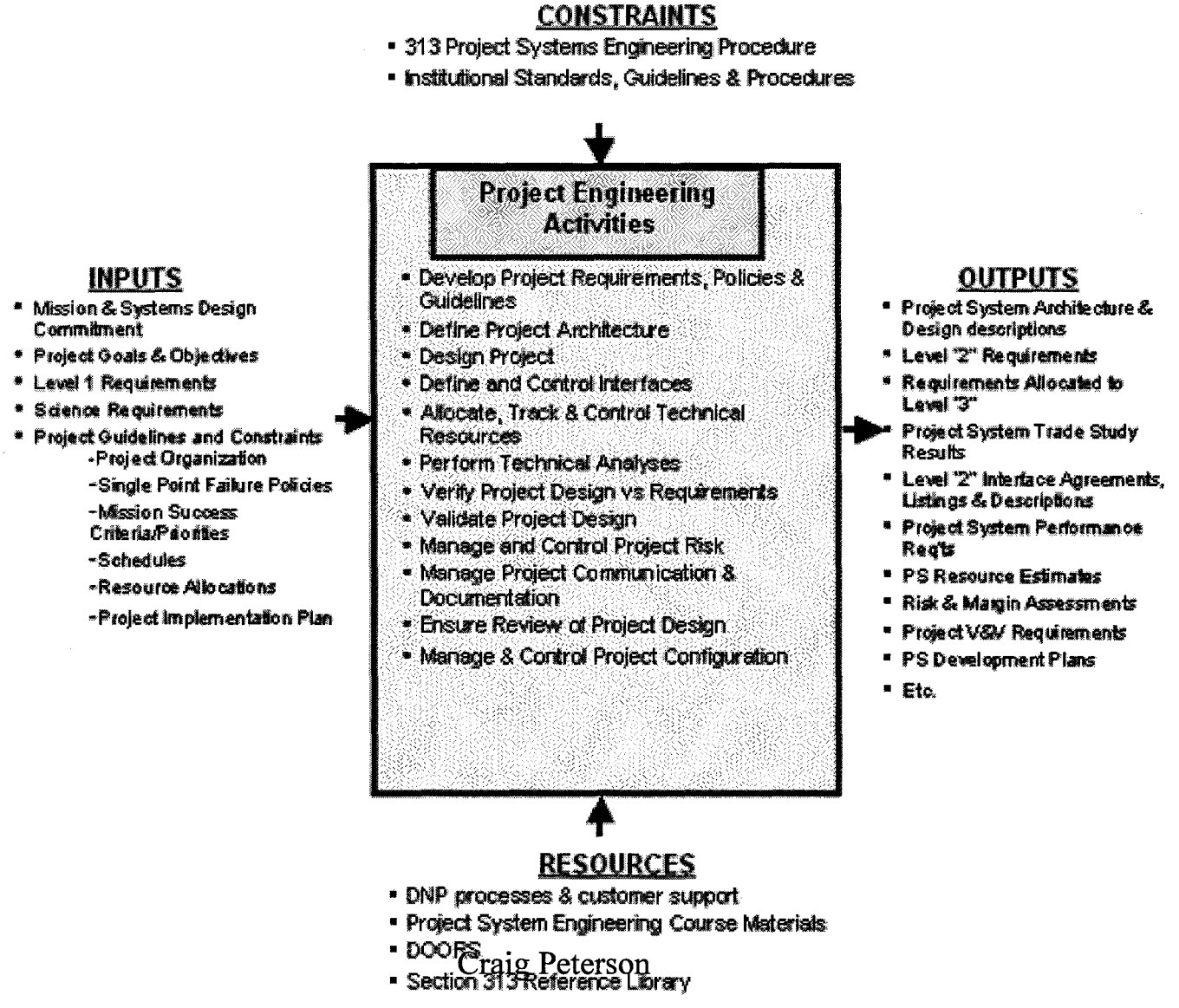
The System Engineering Process



The Past, continued

From JPL SE Course 1994

- **Design Teams**
- **Mission Trade Studies**
- **System Contracting**
- **Design to Cost**
- **System Definition**
- **Requirements Definition**
- **Systems Analysis**
- **System Architecture**
- **Design Trade Studies**
- **Technical Margin Management**
- **Detailed Interface Definition**
- **System Reliability**
- **Design Issue Resolution**
- **Integration and Test**
- **PFR Support**
- **Operations Support**
- **SE for small spacecraft**

The Present

- Faster Better Cheaper =Smaller
- More tools, more data, less time
- Concurrent engineering processes
- Collaborative engineering processes
- COTS Capability driven design
  - from large standard architectural elements to reusable components
- Risk as an element of trade studies
- Greater focus on handling exceptions
- Technology insertion

Tools and Concurrent Engineering

- Worst case analysis (point design)
- Model based design to capture dynamic system behavior
  - Generic modeling tools or discipline specific
  - COTS and custom built
- Requires operational scenario
- Loosely coupled using generic data base and interfaces
- Tightly coupled using standard data formats
  - at increasing levels of fidelity and precision

Analysis Data Flow Example
Power Antenna

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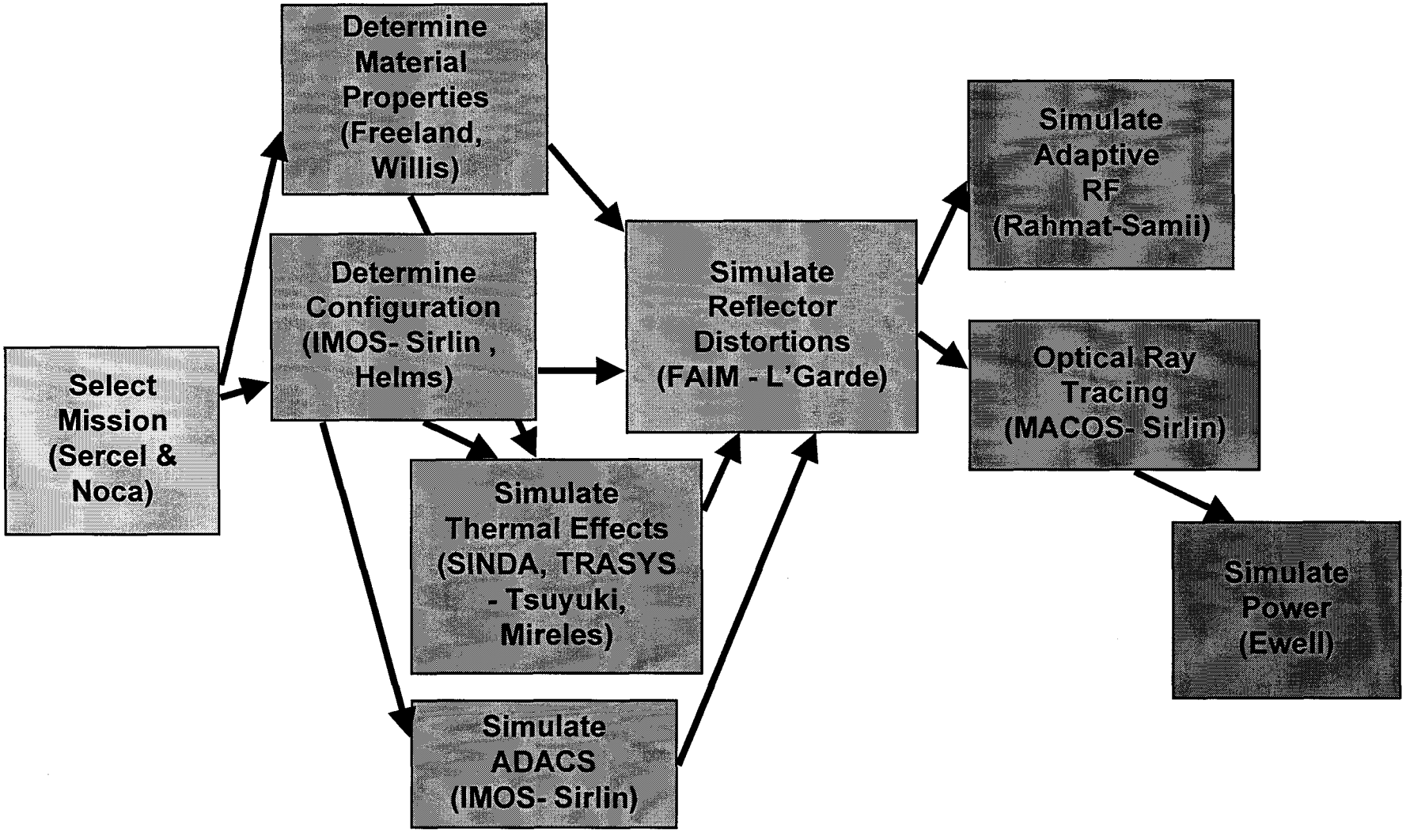

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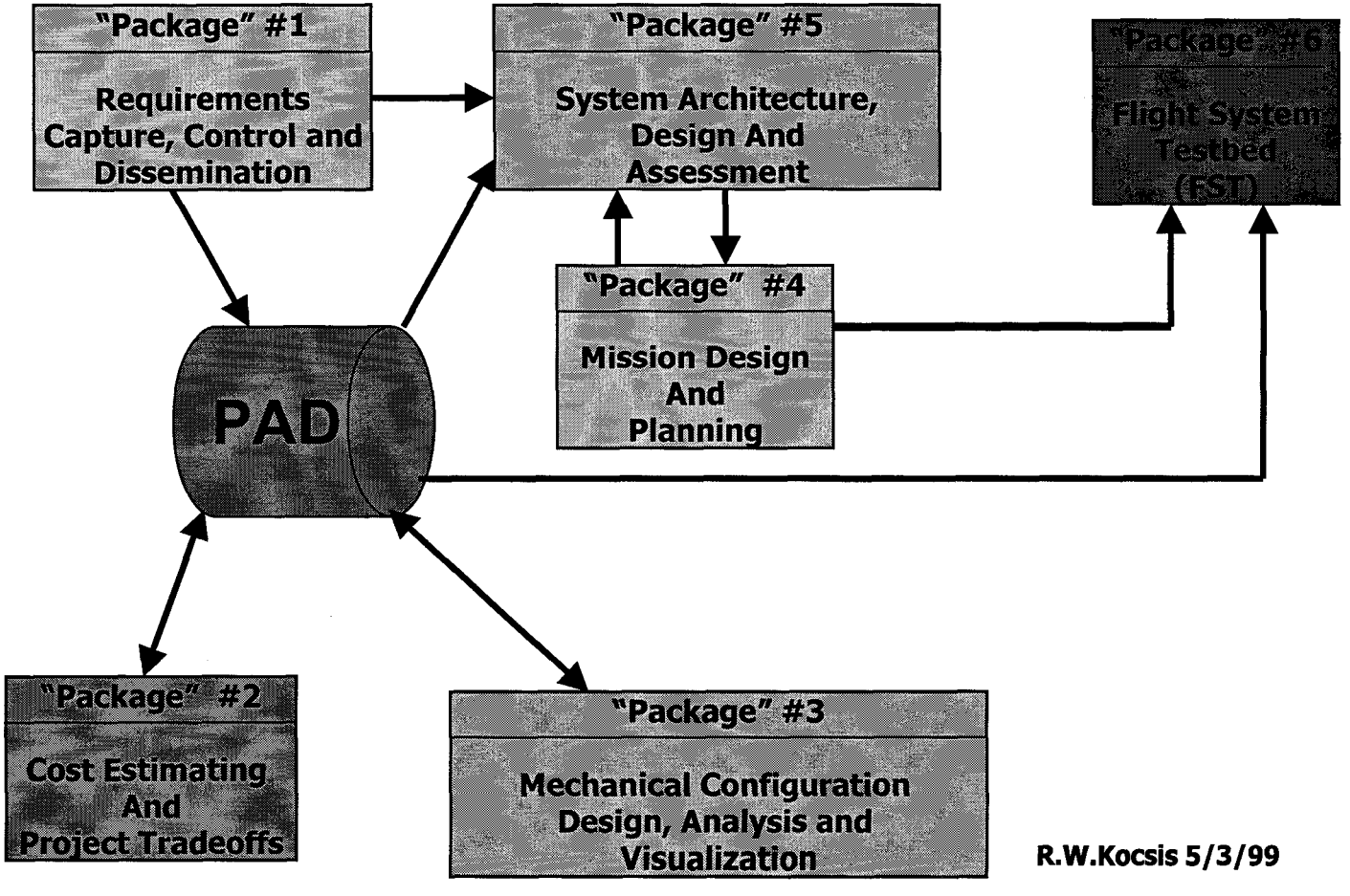
Integration with Database



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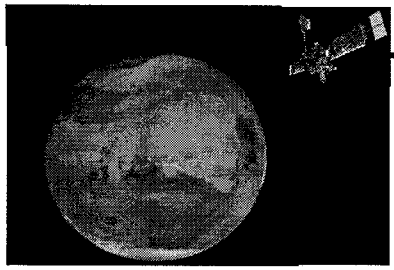
Mars Surface Operations Risk Analysis Framework



Mars Terrain Simulator
(generates high-resolution synthetic Martian terrain)

Computation and Visualization

Rover Ops Monte Carlo Simulation

Plug-and-Play Subsystem Models

Decision Tree
(initializes analysis and computes system reliability cdf)

Computation and Visualization

Database
(mediates transfer of data across models/simulations)

Satellite Orbit Analysis Program (SOAP)

Computation and Visualization

Hardware Reliability Model (HRM)
(computes system reliability for each combination of environmental parameters)

Computation

Component Reliability Database

Rover Equipment List

R. Shishko - 2000

Risk Management

- What is severity of the [negative] consequences of specific failures?
- What is the likelihood [probability] of specific failures?
- The combination of the above is the risk related to a specific failure
  - usually treated semi-quantively (binned)
  - unacceptable risks must be addressed in the design and operations
- Reviewed and status'd just like any other critical resource

Exception Handling

- The system engineer is [usually] the first to know if the overall system design is in trouble
- Margin management =critical system resource allocation and management
  - mass and power, radiation dosage, valves, etc.
  - not just the value at a point in time, but includes design value trajectory extrapolation over time
- Four R's
  - Recover and Reallocate: can be done multiple times without serious consequences
  - ReDesign: depends on the extent of the redesign
  - ReScope: requires customer approval

Technology Insertion

- Short development cycles means technology cannot be developed as part of the project
- Technology development is inherently risky
  - in terms of both cost, schedule, and performance
- No spacecraft development manager wants to depend on someone outside of the organization to deliver the right stuff in a timely fashion
- Actually comes down to a trade of cost, benefit, and risk

The Future

- **Integrated Modeling and Analysis**
  - **libraries of high fidelity component and subsystem models**
  - **allowing for faster iterations on design concepts**
  - **systems requirements to design to system test data flow**
- **Artificial Intelligence for global optimization of trade spaces, however**
  - **design models are inherently non-linear**
  - **iterating non-linear systems can easily result in chaotic behavior**
    - **will require development of mitigating techniques**

A Few Conclusions

- System engineers are increasingly dependent on their people skills
  - communication *and* teamwork
- Increasing automation will not change that
  - except to give SE's more time to work the people issues
- A new job
  - making sure all the automated models are in sync with reality
- An old job
  - understanding the disciplines well enough at both an intuitive and explicit level to spot inconsistencies and miscommunications